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MEMORANDUM REPORT BRL-MR-3754

BRL

JUN 23 1989

AN INTEGRATED ENVIRONMENT
FOR ARMY, NAVY AND AIR FORCE
TARGET DESCRIPTION SUPPORT

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MAY 1989

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U.S. ARMY LABORATORY COMMAND

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			Approved for Public Release; Distribution Unlimited.		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-MR-3754			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION US Army Ballistic Research Laboratory		6b. OFFICE SYMBOL (If applicable) SLCBR-VL-V	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21005-5066			7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
					WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) An Integrated Environment for Army, Navy, and Air Force Target Description Support					
12. PERSONAL AUTHOR(S) Deitz, Paul H., Mermagen, William H., Jr., and Stay, Paul R.					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day)	
15. PAGE COUNT					
16. SUPPLEMENTARY NOTATION Presented as a paper at the ADPA - 10th Symposium on Survivability/Vulnerability, Naval Ocean Systems Center, 10-12 May 1988.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	BRL-CAD PATCH/FASTGEN		
			Computer-Aided Design Ray Tracing		
			COM-GEOM Solid-Geometric Modeling		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) BRL-CAD is a solid-geometric modeling package which has as its origins a project seven years ago to provide an interactive graphics editor for BRL target geometry. Today BRL-CAD represents a suite of software supported by some 150,000 lines of source code to provide 1] an interactive solid geometric editor, 2] powerful ray tracing utilities, 3] a lighting model, and 4] many image-handling, data comparison, and related supporting utilities. This code runs on many machine architectures which utilize UNIX including Sun and Iris workstations, DEC VAX, Gould, Ridge, Pyramid, Elxsi, Convex, Alliant and Cray X-MP/48 and Cray 2 computers. The BRL-CAD source code has been distributed to over 300 computer sites around the world. Until about four years ago, BRL-CAD only supported the original six COM-GEOM primitives. More recently BRL-CAD has been extended so as to support a boundary representation (or B-Rep) scheme using a spline type due to University of Utah. (Continued on reverse side)					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL Paul H. Deitz			22b. TELEPHONE (Include Area Code) 301-278-6644		22c. OFFICE SYMBOL SLCBR-VL-V

18. SUBJECT TERMS (Cont'd):

Splines
Vulnerability Analysis

19. ABSTRACT (Cont'd):

During the current fiscal year, the Joint Technical Coordinating Program (JTTCG) has contracted with the BRL to further extend the geometric domain to support the so-called PATCH geometry developed by Denver Research Institute and used by a significant portion of the Navy and Air Force vulnerability/survivability community. At the completion of this effort it will be possible for the vulnerability community to generate, modify, view, and interrogate a mixture of geometries from the PATCH libraries (>200 vehicle descriptions) or the BRL MGED libraries (>150 models) through the use of this single set of integrated tools.

In this paper, BRL-CAD will be illustrated including the complete set of inhomogeneous geometric data types now supported, a new set of shot-lining utilities capable of execution in fully parallel environments, and the upgrade of faceted geometry using spline surface fitting methods. The last feature is critical in order to support certain high-resolution signature codes for which faceted geometry gives spurious results.

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I. INTRODUCTION

For more than 40 years the vulnerability community has been developing analytic methods to predict the potential damage to targets from threats likely to be encountered in hostile engagements. Early methods of analysis consisted of manual calculations for bullet/target interactions. From the beginning, target geometry and material specifications were required input to the calculations. Such inputs were manually derived through use of blueprints and other system data. By the 1960's, the first attempts were made to apply machine-processing methods to problems of vulnerability assessment.

Two similar, but distinct, methods arose in the vulnerability community. One called the COM-GEOM/GIFT technique was developed by MAGI [1-4] for use by the US Army; the other called PATCH/FASTGEN was developed by FALCON [5] (now Denver Research Institute [DRI]). However the method of approach for each was identical. To perform a vulnerability analysis 1] a target description had to be generated. This file represented the three-space definition of geometry and coupled material information. 2] Mathematical rays, simulating bullet trajectories, were then passed through the target descriptions in order to find points-of-intersection, surface normals, line-of-sight thicknesses, and materials. 3] All of the information from step 2] was then passed to a vulnerability analysis where penetration relations and component-damage criteria were applied to calculate average system-level damage.

The difference between the COM-GEOM/GIFT and the PATCH/FASTGEN methods was principally in the schemes used to represent geometry. In the case of COM-GEOM, a set of simple shapes (called primitives) was defined, including four to eight-sided planar enclosures, an ellipsoid, a general cylinder, a general conic section, a torus, and a (constrained) faceted, self-closed shape used to model compound surfaces (such as cast turrets and aircraft bodies).

By contrast, the PATCH data base consisted uniformly of an (unconstrained) faceted representation. In each approach, the target description was developed by hand, with few automatic aides, and with none of the computer-aided design (CAD) assists that are familiar to all today. The bullet trajectory/material information was extracted from a COM-GEOM file via the GIFT code [6] and from a PATCH file via the FASTGEN code [5].

Over a period spanning more than fifteen years, two significant communities of vulnerability workers have developed generally using one or the other method. Because of incompatibilities between the geometric data structures (COM-GEOM vice PATCH), resources of one community were expended to replicate geometry already pre-existing in the other because of the incompatibilities of the techniques. Also, it can be assumed, useful analyses were foregone because existing target

descriptions were incompatible and resources/time were insufficient to perform a duplication.

Against this background the BRL initiated some nine years ago a program with a goal to introduce modern methods of interactive computing to the problem of geometry generation, modification and interrogation. The initial task was to build an interactive editing environment so that BRL COM-GEOM descriptions no longer had to be built by hand. Later new ray casting utilities were generated to replace the old GIFT program used for many years. Also many image-handling and geometric data manipulation utilities were written to perform useful tasks. This suite of programs has become known as BRL-CAD [7] and consists now of some 150,000 lines of source code. This package has been distributed to over 300 computer sites around the world and supports a significant number of vulnerability, signature, and structural-analysis programs.

The aim of this paper is to summarize the chief properties of the BRL-CAD package, and particularly update current efforts to extend the old COM-GEOM data base to include both spline surfaces as well as the PATCH data base of DRI. This last extension represents a significant development for the US vulnerability community for finally both dominant target description techniques are supported within one consistent environment. With these advances, COM-GEOM, splines, and PATCH geometries are fully supported both for editing and shotline interrogation. Further, the various geometries can be used in "pure" form or in a "mixed" mode.

II. OVERVIEW OF BRL-CAD

The BRL-CAD package is written exclusively in C-code using structured coding methods. Individual processing modules are designed to support specific capabilities. Copious use is made of the "library" concept of software organization. By this method, software modules of general utility to a group of users are installed as system utilities and called by other programs under the control of the users themselves. This makes the individually tailored user programs much simpler, reduces greatly the volume of code maintenance, and allows utility upgrades and bug fixes to be available to all in an automated fashion. BRL-CAD is comprised of some 70 individual programs. Some of the principal elements are:

- *mgd*: Standing for Multiple-device Graphics Editor [7-9], *mgd* is an interactive editor for constructing and updating target descriptions of the COM-GEOM variety. Support is there for editing the basic six primitive shapes of COM-GEOM. Screen prompting is via a wire-frame representation of the solid-model data base. Many user aides have been added over the years including the ability to switch instantly between English and metric units, calculating volumes, surface areas, and (armor) fall-back angles for various shapes, region overlap checking; also commands to assign material property to regions, save a view for ray-tracing, and many others. The

display-oriented approach to building the COM-GEOM data bases is very easy to learn and can be used to build complicated models in a short time. Mged allows several graphics display devices to be used by the community for building COM-GEOM data bases. Some of the graphics devices include the Megatek 7000 vector display, Silicon Graphics Iris and 4D graphics workstations, Sun workstations, Tektronix vector displays, and Evans and Sutherland PS 300 graphics terminals. Recently added was a driver for the X Window System, which is used by many graphics display workstations vendors as a common graphics interface. Porting mged to new graphics devices is a straight-forward task and takes a short time to accomplish.

- *librt*: A library of functions suitable for ray tracing a target description file
- *rt*: A lighting model whose input is based on ray tracing (*via librt* support). Up to ten light sources can be simulated, and objects can be given the properties of mixed diffuse and specular scattering, and refraction
- *libfb*: A generic frame-buffer library which includes support for a number of display devices, as well as file, network, and debugging interfaces.
- *libplot8*: A public-domain version of the UNIX-Plot library has been extended with the following features: three-dimensional plotting support, 24-bit RGB color values, and floating-point values. These values are written into the plot file in a transportable, machine-independent binary format and can be used between different machines connected *via* a network.
- *util*: A collection of image-handling utilities, each constructed as individual tools intended to be used in combination. Such functions as color correction, format conversion, pixel comparison, and image filtering/processing are supported.
- *rfbd*: A "message-passing" interface layered on top of standard UNIX network protocols which allows image data to be transmitted from one computer and displayed on another

BRL-CAD is designed to run under the UNIX™ operating system. This strategy has paid significant dividends by easing the porting of this code over many different computing environments and/or display devices. Some of the computers on which this software runs include:

- DEC VAX-11/750, VAX-11/780, VAX-11/785, VAX-11/8600, & VAXSTATION II GPX
- GOULD PN6000 and PN9000 Series
- Sun Workstations
- ISI 68020
- Ridge 330

- Pyramid 90Mx
- Elxsi 6400 Series
- Convex C1 XP & C2
- Multiflow TRACE 7/200
- Alliant FX/8 & FX/80
- Silicon Graphics IRIS 3000 Series & 4D Workstations
- CRAY X-MP/48 & CRAY 2

III. BRL-CAD GEOMETRIC DATA REPRESENTATION

The heart of a geometric modeling system is reflected in the data representation for three-space geometry. As noted above, BRL-CAD was originally designed to support the six classes of primitives under the old COM-GEOM file structure and to be interrogated by the old ray casting program GIFT [6]. These primitive types are illustrated in Fig. 1. The advantage of geometric description by such primitives is that the mathematical description is generally economic. In the case of the ARBs, the corners are specified. In the case of the second-order primitives (conics, ellipsoids) and the fourth-order primitive (torus), the descriptions are economic too and the surfaces are mathematically smooth. Their economy is also their limitation, in that the degrees-of-freedom of each primitive shape are clearly limited.

In the old COM-GEOM file structure, all of the primitive objects were simply numbered in ascending order. Only numerical designations could be given, so interpretation of objects by name was difficult. The current MGED file structure is hierarchical so that a target description can be constructed in multiple levels of logical groupings. English names can also be assigned. An instancing feature also has been added so that a single object prototype (round of ammunition, vehicle wheel, etc.) can be replicated to multiple positions and orientations in space. By this strategy, if the prototype is changed, all copies change automatically.

For certain classes of analysis, critical errors result if complex geometries are approximated by faceted representations (such as the ARS). In order to accommodate high-precision surface modeling, the MGED data base was extended some years ago to support the Non-Uniform Rational B-Spline (NURB) representation of the Alpha-1 geometry system [10-13]. An example of a part modeled with Alpha-1 is shown in Fig. 2. The strategy followed by the BRL has been to use the Alpha-1 editor, SHAPE-EDIT, to perform the actual construction of spline entities. MGED is then used to read the spline geometry into the target space, supported by global rotate, translate, and scaling capabilities.

A recent extension of the MGED geometry environment has been the inclusion of the PATCH representation used by DRI. The approach used here is to represent all shapes by triangular (patch) regions. For



Figure 1. The set of primitive objects originally supported by the BRL-CAD environment. Basic shapes include the ARBs (four- to eight-sided planar shapes), the ellipsoid, a general cylinder, a general conic section, a torus and a (constrained) faceted object called the arbitrary surface (ARS).

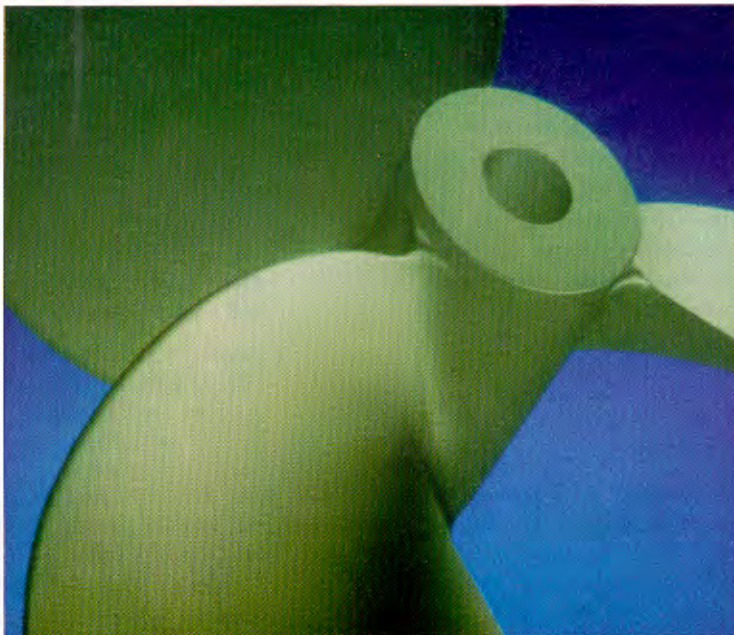


Figure 2. A geometric description of a ship screw built using spline geometry supported by the U. of Utah system, Alpha_1. Such spline geometry can be merged into the BRL-CAD data base. The use of splines to model complex surfaces avoids the use of faceted approximations. For certain applications where high surface fidelity is required, this capability is critical. *(Geometry courtesy of the U. of Utah.)*

flat surfaces, the approximation is exact. For curved surfaces, the degree of approximation depends on the number of facets used to represent the geometry. Figures 3a and 3b show an example of a DRI-created description of an F-14 aircraft. The wireframe image (Fig. 3a) shows the visual support given a target describer while in MGED. Figure 3b shows the rendered version of that aircraft created by the *rt* lighting model program. It is significant to note that the lighting model program was written well before either the PATCH or spline geometries were added to the BRL-CAD environment. Accommodation to interrogate new geometries is achieved entirely at the ray casting process supported in the library function *librt* to be discussed in the next section. However such extensions *do not* change the formatting of data passed from the ray interrogation process, so that all application codes whether a lighting model, as here, or a vulnerability application need undergo no changes whatsoever.

The inhomogeneous data base strategy described above has a number of important features and capabilities:

- Target descriptions for the purpose of vulnerability analysis (or any other application) can now be assembled and interrogated in the single MGED environment. If the geometry in itself is sufficiently accurate, there is no need to perform a "translation" from one representation to another. The approach here is simply to merge, as is, all geometric representations into a single environment. Thus a target description can consist as only PATCH, only spline, only COM-GEOM shapes, or any mixture of the three.
- For some applications, particularly in the area of signatures, faceted geometry (either through use of the ARS or PATCH shapes) embodies surface approximations which introduce serious errors in subsequent analysis. The inclusion of splines, together with surface fitting routines, gives an efficient upgrade path when needed. This capability is illustrated in Fig. 4 in which a US tank turret is shown first in a faceted representation and then transformed into a smooth-body spline shape.
- On the other hand, spline geometry is expensive in terms of data storage and interrogation. For high-detail point-burst vulnerability analysis, many thousands of interior vehicle or aircraft parts must be described. The relatively simple shapes of COM-GEOM adequately reflect the presented area and spatial position of these components without heavily taxing computer storage or processing requirements.

IV. LIBRARY SUPPORT

As noted in Section II, BRL-CAD makes copious use of the library approach to software support. Library routines are executable codes which are installed as part of the standard set code for use by all computer users. A number of the more important library routines are summarized

- *librt*: Several routines which compute the geometric ray/intersection calculations with all primitives in the data base have been included in *librt*. By using these common routines, the applications programmer can place emphasis on modeling and programming the physics of a problem rather than invest time to recode the geometric properties of the model. The application sends the data base and its associated sub-trees to the library. A ray origin and direction are specified; other options include stopping the ray after first, next, or all object intersections. The library then performs the following calculations: 1) space partitioning, 2) bounding volume calculations, 3) ray/geometry intersections, and 4) boolean evaluations, and performs both parallel and vector execution, if available. The library then can return the following information to the application if needed: 1) hit points, 2) distance from the ray origin, 3) surface normals, 4) material property, and 5) surface curvature. The library is designed such that new primitives can be added easily to the system. Using this feature both NURBS [14] and PATCH models were added to the BRL-CAD system.

- *libfb*: The framebuffer library provides device-independent access to raster displays for displaying a common image format consisting of pixels of red, green, and blue values. There are several device drivers to support a variety of displays including Adage Ikonas, Silicon Graphics IRIS 3030 and 4D, Sun, and AT&T 5620 terminals. There is also a debug and disk interface. The library is designed to provide isolation from the low-level functions necessary to interact with the display hardware. This library uses the *libpkg* library to support display devices connected to other machines on the network. Library routines supporting the following operations are available for displaying images: open, close, zoom, pan, read/write pixels, read/write color maps, and cursor manipulation.
- *libwdb*: The *libwdb* library permits writing of MGED data bases from arbitrary programs. Though it does not currently have the full spectrum of MGED primitives, it does include the following primitives: half-space, rectangular-parallelepiped, arb4, arb8, sphere, ellipse, torus, right circular cylinder, truncated right cylinder, spline, and facet. In addition, this library permits the creation of "regions" and manipulation of their material property parameters.

This new capability has made conversion from other geometrical data base types to MGED easier to implement and hence more efficient. In particular, the conversion code that converts PATCH descriptions into MGED data bases makes significant use of the *libwdb* library routines.

V. OTHER INTERFACES TO APPLICATIONS CODES

As noted in Section IV, ray casting in BRL-CAD is supported *via* the *librt* routines. Ray casting has always

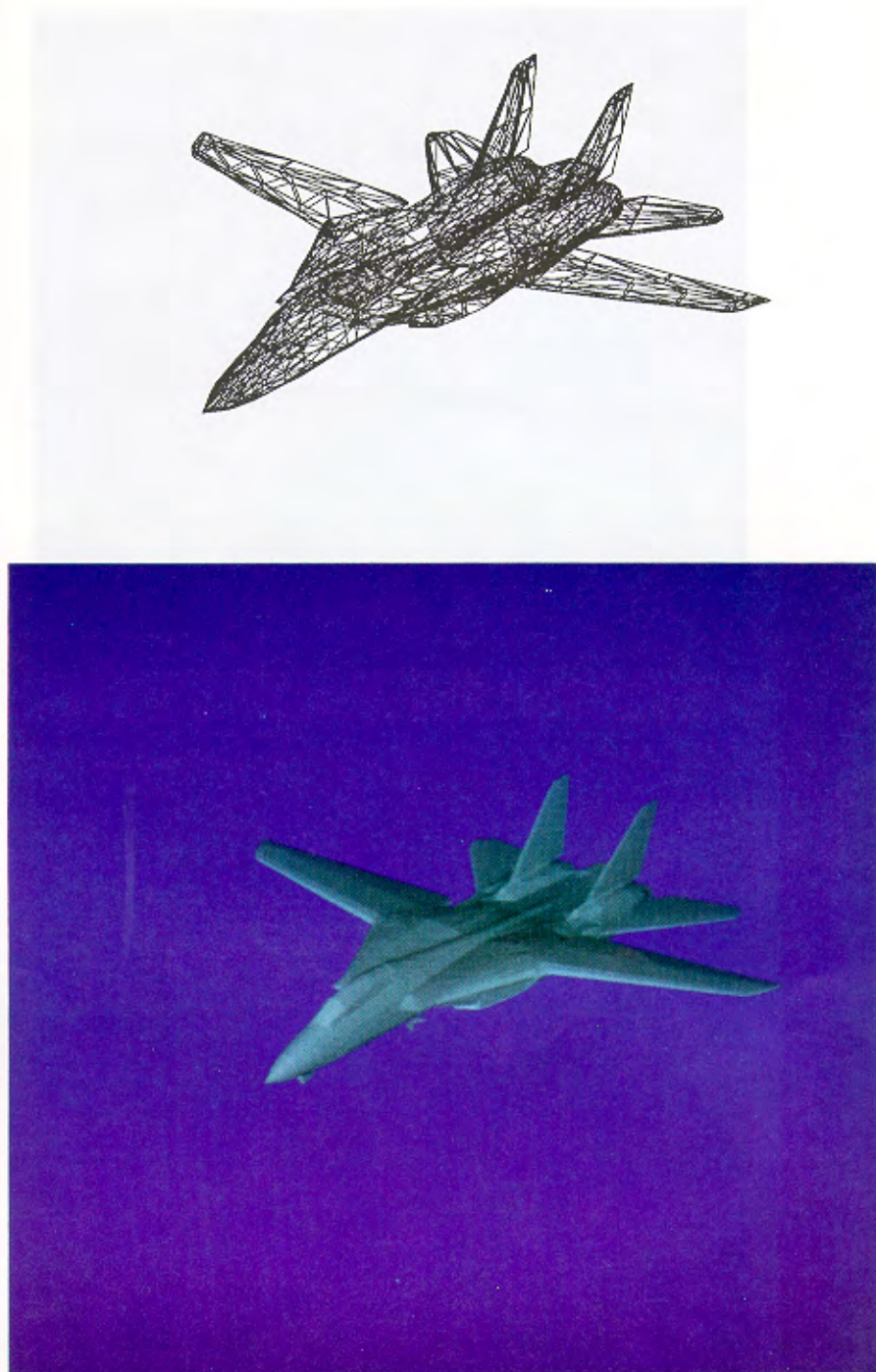


Figure 3. Part of a F-14 target description built using PATCH geometry due to DRI. The geometry on the top is shown as it appears when displayed by the graphics editor, MGED. The wireframes bounding triangular regions delineate the edges of the individual patches. The image on the bottom shows the object following rendering with the BRL *rt* lighting model. (*Geometry courtesy of DRI.*)



Figure 4. Images of an M48 tank built originally with a faceted turret on the top. On the bottom is illustrated the same turret after upgrading through the use of a spline fit. *(Geometric model by P. Stay, BRL.)*

been central to vulnerability analysis in order to simulate bullet trajectories. It is also used by many other applications codes including lighting models and various programs to predict signatures.

It is important to note, however, that there are other approaches to linking geometry to applications. These have been discussed elsewhere [15], but are summarized briefly here:

- **Topology:** Certain radar codes use a representation of geometry consisting of various canonical shapes such as flat plates, dihedral, and trihedral surfaces. Utilities have been generated which can be used to process a MGED target description to extract these shapes *via* processing filters.
- **3-D Surface & Volume Meshes:** Many important mechanical and structural codes (ADINATM, NASTRANTM, etc.) are supported by such mesh structures. In order to support meshes which are direct derivatives of MGED geometry, a commercial modeling system called PATRANTM has been linked *via* a translation code [16]. This conversion program maps each of the COM-GEOM primitives into the corresponding representation in PATRAN. Then PATRAN is used to generate the desired mesh.
- **Analytic Representation:** Each of the COM-GEOM primitives can be mapped into splines; the same is true for any PATCH object. Splines are one of the few geometric representations which can be manipulated analytically. One such property is that splines can be Fourier transformed. A number of radar modeling groups have attempted to take advantage of this and related properties.[17]

VI. OTHER UTILITIES/CAPABILITIES OF BRL-CAD

- **Lighting Models:** Two ray tracing programs that use the ray casting support of *librt* are provided in the BRL-CAD package, *rt* and *lgt*; *lgt* is an optical rendering program with a screen-oriented user interface. *lgt* has the ability to provide animation scripts and laser target renderings. *rt* also provides rendered images with command line arguments, but is itself the front end for several applications including a radar model. *rt* also has the ability to read scripts of commands which can control the computation of a sequence of frames and the orientations and properties of materials in each frame of an animation.

Figures 5 and 6 show exterior views of the Bradley Armored Fighting Vehicle rendered using *lgt*. The target description used here is extremely detailed so as to support a high-frequency radar simulation. Figure 7 illustrates a lighting model option in which armor is rendered transparent so that internal component placement can be viewed.

- **Animation:** The continuous control of viewing position and/or the changes in relative geometry are of growing importance both as a tool to understand

geometry itself as well as key to many applications including the multi-spectral signature area. The control of animation is achieved in the following fashion. Using *mgcd* a few frame positions (keyframes) can be selected using the *saveview* command. After multiple keyframes are generated, the program *zlate* fits a spline curve to the saved frames and generates additional frames to create a smooth animation sequence. The *rmats* command within *mgcd* will read processed frames to inspect the wireframe version of the animation, which can then be used to generate a series of images that can be transferred to video tape.

Ray Tracing Benchmark Results		
Rays/Sec	VAX /780	Machine
107.7	0.96	VAX Station II GPX
112.1	1.00	VAX 11/780
119.0	1.06	SGI IRIS 3030
127.3	1.14	Sun 3/50
191.8	1.71	VAX 11/785
413.4	3.69	GOULD 9080
521.1	4.64	VAX 11/8600
571.0	5.09	Sun 4/260
982.8	8.76	SGI 4D/60T
3972.9	35.44	Alliant FX/8, 8 CEs,
5376.3	47.96	Alliant FX/80, 8 CEs
7275.8	64.90	Cray 2, 4 CPUs,
13320.2	118.82	Cray XMP/48, 4 CPUs,

- **Benchmarking Support:** Finally, as the capabilities and costs of computing change rapidly, it is important to understand the benefits and limitations of the growing number of candidate machines and display devices in the market place. This has been achieved in part by utilizing a number of standard benchmarks for processing standard target-description/lighting-model images. The above table shows the results of running the program *rt* with a common data base and comparing them with the speed of a Digital VAX 11/780.

VII. APPLICATIONS CODES WHICH INTERFACE TO BRL-CAD

There is a large number of applications codes which interface to BRL-CAD. They have been enumerated in some detail elsewhere [18], and are simply listed below:

- Weights and Moments-of-Inertia
- An array of Vulnerability/Lethality Codes
- Neutron Transport Code
- Optical Image Generation (including specular/diffuse reflection, refraction, and multiple light sources, animation, interference)
- Bistatic laser target designation analysis
- A number of Infrared Signature Codes
- A number of Synthetic Aperture Radar Codes (including codes due to ERIM and Northrop)



Figure 5. Frontal view of the Bradley Armored Fighting Vehicle using the BRL *lgt* lighting model. The geometry, built with MGED and only the primitive shapes illustrated in Fig. 1, is highly detailed so as to support high-frequency radar simulations. (*Geometric model by K. Applin, BRL.*)



Figure 6. Rear view of the Bradley Armored Fighting Vehicle calculated as in Fig. 5.
(Geometric model by K. Applin, BRL.)

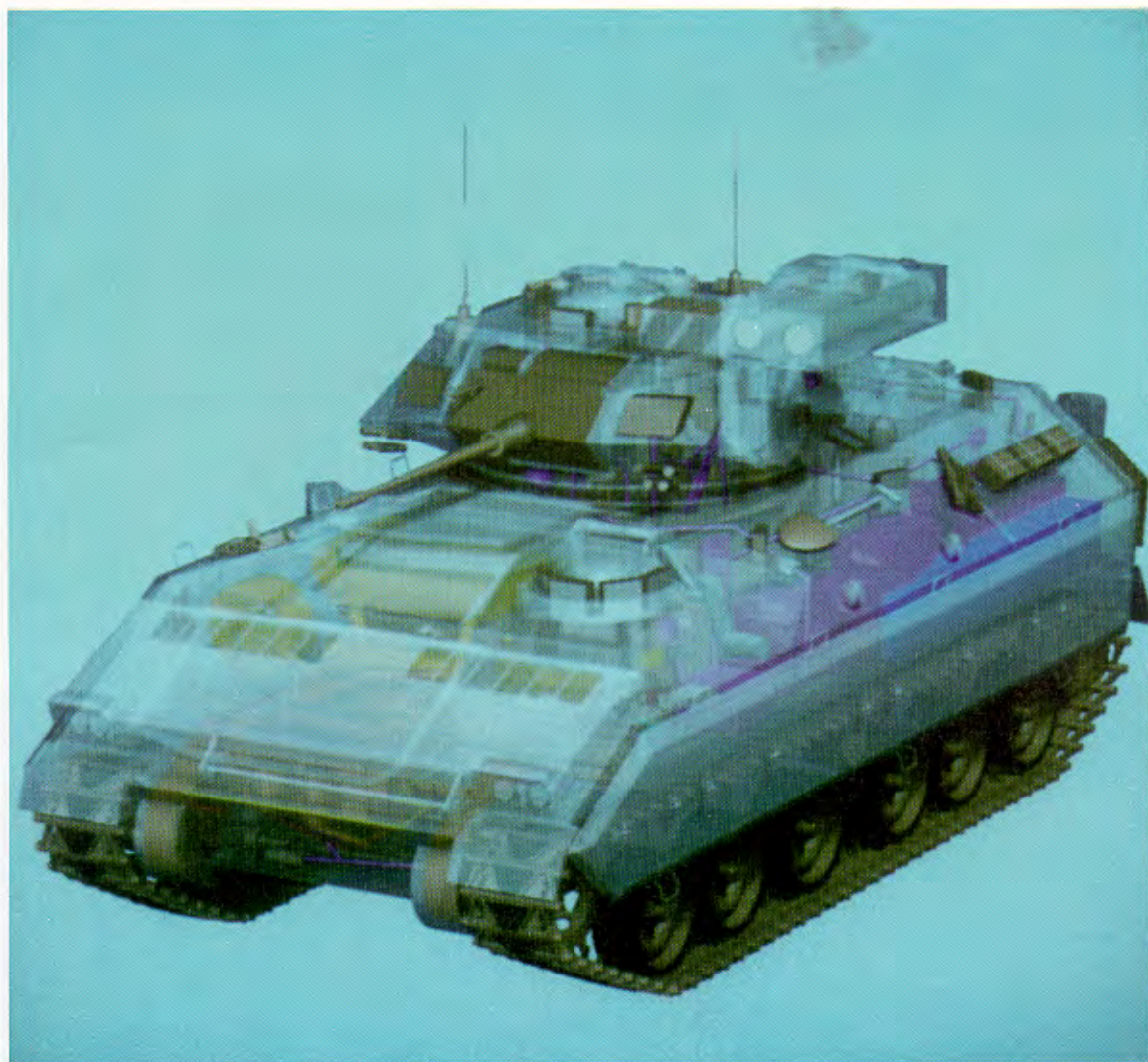


Figure 7. Transparent rendering of the Bradley Armored Fighting Vehicle. Using the same target description file as in Figs. 5 and 6, a lighting model option allows armor to be rendered transparent, revealing internal component placement. (*Geometric model by K. Applin, BRL.*)

- Acoustic modal predictions
- High-Energy Laser Damage
- High-Power Microwave Damage
- Link to PATRANTM and hence to ADINATM, EPIC-2TM, NASTRANTM, etc. for structural/ stress analysis
- X-Ray Imagery

VIII. WORK IN PROGRESS/EXTENSIONS

There are a number of projects underway which will greatly extend the utility of the package. Some of these are:

- Translations to Facets: The flat-sided objects such as the ARBs, ARSes, and PATCHes, are, by definition, facetized. Objects which are represented by facets have important utility for certain types of display and data representation. In order to achieve the ability to generate homogeneous facetized geometry, algorithms are being investigated to convert each of the higher-order representations into a facetized approximation in which facet size is under user control. A more difficult issue is the resolution of overlapping primitives. In the shotline interrogation process, boolean definitions (UNION, INTERSECTION, DIFFERENCE) are used to logic process the geometric rays. The resolution of boolean precedence along a single line is a relatively simple operation. The boolean resolution of overlapping meshes is much more difficult.

There are a number of important payoffs for extensions along these lines. A direct translation of the mixed MGED data base to facets would achieve the following objectives: 1) Support of codes mentioned above which require 3-D surface meshes would be direct. 2) Also, many modern display devices support real-time polygon fill capability via hardware. This provides for much more realistic object rendering than the usual interactive wireframe images.

- Automated Drafting: In previous years the BRL has seldom needed to generate standard blueprints from its solid geometry. Nevertheless, such a capability would be a useful extension. A program is being put in place to make this improvement *via* a small business contract.
- Data Base Extensibility: We note again that the current BRL-CAD geometric data base is distinctly non-homogeneous. When another modeling scheme has been used to represent geometry, and when it is important to utilize that geometry in the BRL-CAD environment, there are two paths to compatibility. The first is to see if the new geometry has an exact, corresponding representation with the current BRL-CAD primitives. If so, it is simply a data reformatting job to make a MGED-readable input file. However, if the new geometry does not correspond to any current structure (previous

examples include both the spline and the PATCH data bases), then the current MGED data base is simply extended to include the desired representations. This requires work at two distinct points. The first is in the formatting of the MGED data base and the graphical imaging and manipulation tools in the MGED editor itself. The second point is in *librt*; there the ray casting tool must be modified so that it knows how to perform the intersection, surface normal, curvature, etc. calculations. However, once these changes are made, no other modifications are required, and all application codes run with no change.

IX. SUMMARY

In this paper we have described a unified set of software which brings the two major geometric data bases used for vulnerability analysis under a single integrated environment. Spline surfaces are supported as well, making available an important growth path when high-precision geometry is required for demanding analyses.

Because of these efforts, it is no longer necessary to duplicate identical target geometry because of two incompatible representations. In fact, mixed modes of targets can be assembled using arbitrary combinations of COM-GEOM, PATCH, and spline data bases.

This software has been designed to run on more than a dozen brands of vendor hardware. Machines from the SUN Workstations to the CRAY 2 are supported. Since the source code for all of this software is Government owned, it can be ported to any desired target machine without cost of royalty or suffering vendor constraint.

Finally, the code has been built in modular blocks. This makes for easier development and enhancements. It is to be expected that the evolution of this package will continue to reflect both user needs and the rapid development of higher speed machines and display devices.

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